Dynamic prediction of CH4 emission in longwalls

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DYNAMIC PREDICTION OF CH_4 EMISSION IN LONGWALLS

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SUMMARY

Methods for predicting mean CH_4 emission in longwalls have been developped in France and other countries for many years. These methods have been widely validated but remain limited in their use because of the continuous increase in productivity of such working.

Therefore, development of dynamic prediction methods - e.g. allowing prediction of emission on a daily or weekly basis - is strongly necessary.

Aiming to that, two ways have been investigated :

- a statistical approach. Analysis of CH_4 emission of 14 faces has allowed building the expression of the emission during a given week as a function of mean predicted emission and of advance (or production) of the three previous weeks.

- a mathematical modelling of CH_4 emission as a function of stratigraphy and of gas content of the strata surrounding the mined seam. Analytical expression contains numerous parameters that must be adjusted using a reference face, so as to be able to carry out a real prediction for later workings.

INTRODUCTION

Prediction methods have been largely tried and tested for a number of years but remain limited due to the increase in the productivity of workings. The advance rate of longwalls can be very high, which has two consequences:

- the time required for the emission to build up at the beginning of the panel is sometimes relatively high,

- the variations in emission with regard to the average are also important.

The methods used to predict the average emission are not sufficient to account for these two phenomena (see Figure 1). Dynamic prediction methods therefore need to be developed which will enable the day-by-day or week-by-week emission to be ascertained as a function of the activity of the previous periods. Most of the authors who have examined the problem use a statistical approach to predict firedamp emission. They propose taking the average, the dispersion and the frequency of the emission values as the characteristic parameters of this phenomenon (Bruyet, 1967; Borowski, 1969; Winter, 1972).

This approach enables the "normal" emission level to be defined, as well as a safety factor resulting from the

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probability of deviating from this level. However, it does not enable a real prediction of the emission to be made as a function of the activity.

Another approach which contains a certain amount of dynamic prediction has already been proposed (Kaffanke, 1980). Kaffanke expresses the firedamp emission for each day of the week as a certain combination of several factors (production of the day in question, cumulated production of the previous days). The functions used to calculate the daily emission are different for each day of the week. The factors proposed as having an influence on the emission of firedamp are not related to the physical mechanisms. The success of the Kaffanke model therefore rests, to a large extent, on the low variability of the weekly production cycles.

An approach has also been proposed based on the hypothesis that the gas emission during a given day depends on the production of that day and on that of a certain number of previous days (British Coal, 1988). In this model, the function expressing the emission is applied in the same way to all the days of the week.

The constants of this function are calculated for a given working according to the emission values measured in this very working. Once the constants have been determined, the firedamp emission is predicted for the remaining part of the working.

METHOD USED IN FRANCE TO PREDICT THE AVERAGE EMISSION IN LONGWALLS

The method widely used in France for predicting firedamp emission in faces was developed more than 25 years ago (Gunther, 1965). It has been improved on several occasions, and particularly in recent times (Jeger, 1980; Ineris, 1992). This model is based on several fundamental observations :

- The emission of firedamp is the result of partial degassing of the coal seams and rock beds situated in a volume of influence at the roof and the floor of the seam being mined. After a certain advance of the face, corresponding to the extension of the volume of influence, it becomes stabilized (see Figure 2). The limits of the volume degassed by a face are in the order of 170 meters for the roof and 60 meters for the floor of the mined seam.

- In the volume of influence, the desorbable gas content of a seam decreases from its initial content to a final residual content. This residual content depends on the distance of the seam being considered from the seam being mined. Figure 3 indicates the degassing rates of the affected seams. For the mined seam, a degassing rate of 50 % is usually taken.

- In the volume of influence, the rock beds also release part of the firedamp initially compressed in their intergranular voids. The amount of gas released is calculated according to the porosity of the rocks, the initial in situ pressure and the residual pressure (Ineris, 1992).

The specific emission is calculated by dividing the sum of the basic volumes of gas released in the volume of influence by the number of tonnes of coal extracted (or by the advance of the face). This ratio therefore represents an estimate of the volume of CH_4 likely to be released per tonne of extracted coal (or per meter of advance).

Under the geological and operating conditions of the Lorraine Coalfield, this method gives a satisfactory degree of precision. The discrepancy between the predicted emission and the emission actually observed is in the order of ± 10 to 20% and only goes outside this range in very special cases (see Figure 3).

However, it must be remembered that this calculation to predict the specific emission only gives an average value for the lifetime of the face, after its initial starting period.

DYNAMIC PREDICTION USING A STATISTICAL APPROACH

Observation of the firedamp balance in a large number of faces has shown the pertinence of the hypothesis already made (British Coal, 1988) by which the gas emission over a week depends not only on the week's advance, but also on the advance of a certain number of previous weeks.

In order to carry out investigations aimed at confirming this idea, a data base for the firedamp balance of a representative set of coal mines in the Lorraine Basin has been created. The faces selected met the following conditions: dip of 15° to 30°, opening of 2.5 to 4.0 meters, caving, length of face 200 to 300 meters, advance rate 10 to 40 m/week. In order to determine the relationship between the emission for a given week (n) and the advance of a previous week (n-x), linear regressions were carried out. The results, which are based on all the data in the life of the faces since their starting, are presented in Figure 4. Since they did not prove conclusive, it was noted that one factor in particular strongly influenced the statistical relationship between these variables. This factor is the increase in the firedamp emission after the face begins, corresponding to the expansion of the volume of influence.

An analysis was then carried out of the correlation between the specific emission and the cumulated advance of the face. This was used to determine the average value of a "critical length" for the Lorraine Basin faces i.e. the cumulated advance for which the face is in steady state with regard to firedamp. The value found is about 220 m (see Figure 5).

Elimination of part of the data corresponding to cumulated advances of less than 220 meters considerably improves the results of the previous linear regressions (see Figure 6).

After carrying out a statistical Student-Fischer test to check that the correlations are significant, it can be said that the volume of firedamp released during the week depends in practice on the advance during that week and those during the previous two weeks. In general, this dependence is much greater for the advance of the week in question and decreases with time, which is in accordance with the physical firedamp emission models (Gunther, 1965; Ettinger, 1966; Airey, 1971).
The emission D_n for week n can thus be expressed as follows :

$$D_n=D_s[a_nA_n+a_{n-1}A_{n-1}+a_{n-2}A_{n-2}+C_a]$$

where :

- D_n is the emission for week n, in m^3,
- D_s is the specific CH_4 emission of the face, in m^3 per meter of advance,
- A_n, A_{n-1}, A_{n-2} are the advances of week n and the two previous weeks,
- a_n, a_{n-1}, a_{n-2}, C_a are constants.

Using a multiple regression analysis between the weekly advances A_n, A_{n-1},

A_{n-2} (which are independent variables) and the weekly emission D_n (which is the dependent variable), the values of the constants in equation (1) were found for a set of 14 faces.

Significant correlations with a physical meaning (positive values of constants) were obtained for 7 faces. The results are presented in Table 1. It should be noted that the majority of the faces for which non-significant correlations or nonsensical constants were obtained are either faces affected by other workings or faces for which very intensive drainage has occurred.

Given the relatively low variation in the values of the parameters obtained, average values were taken (see Table 1). Thus, the following formula can be used to predict the firedamp emission according to the advance of the face being considered :

$$D_n=D_s[306A_n+150A_{n-1}+75A_{n-2}+5470) \quad (m^3) \quad (2)$$

where :

- D_n is the expected volume of firedamp for week n, in m^3,
- D_s is the specific emission, obtained using the method described previously (chapter 2), in m^3 of CH_4 per meter of advance,
- A_n is the planned advance for week n, in m,
- A_{n-1} and A_{n-2} are the real advances for weeks n-1 and n-2 in meters.

A similar formula can be obtained by expressing the emission for week n as a function of the tonnage produced during weeks n, n-1 and n-2.

The use of this method for several faces has produced very promising results, even for faces affected by other workings or those with intensive drainage. Figures 7 and 8 give a comparison, by way of example, of the weekly emissions actually observed for two faces and those obtained using the prediction method.

However, this method still needs further examination. The values of the parameters obtained are average values for all of the Lorraine Basin. It should be possible to find the values of these parameters for a specific area or mine, using the regionalized variables method, for example.

Finally, the values of the constants obtained need to be related to physical data, such as stratigraphic data.

PHYSICAL MODELLING PROPOSAL FOR FIREDAMP EMISSION IN A FACE.

It is quite obvious that, although the statistical approach proposed above gives interesting results, it only applies to the period after the face starting phase.

This limitation of the method has led to the search for another model which will enable a dynamic prediction of the firedamp emission to be made throughout the life of a face.

The model proposed below is based on experience acquired in the field of gas emission. It is therefore a physical model based on experimental results.

If we observe the CH_4 emission of a coal or rock bed located at a certain distance in the roof or the floor of the face as a function of the displacement of the face, a curve similar to that given in Figure 9 is obtained (CEC, 1980; Airuni, 1981). The emission rate here is plotted against time which, in the case of a regular advance, is the same thing.

The following can be noted :

- a delay in the beginning of emission, corresponding to extension of the volume of influence up or down to the bed considered,
- a very rapid increase in intensity, corresponding to relaxation of the bed,
- then, after reaching a maximum, a much slower decrease.

For a given period of time, the volume of CH_4 released by the bed will be that represented by the shaded area in Figure 9.

This physical phenomenon can be easily modelled by the following mathematical expression (for the roof) :

for $t < t_0^R$: $\quad f^R(t) = 0$

for $t > t_0^R$:

$$f^R(t) = \frac{1}{\sqrt{2\pi}\,\sigma^R (t - t_0^R)} \exp\left[\frac{-\left[\mathrm{Log}(t - t_0^R) - m^R\right]^2}{2(\sigma^R)^2}\right] \quad (3)$$

This is a log-normal distribution where :

- f^R is the gas release rate for that part of the bed being considered (roof) in m^3/day or m^3/week,
- t is the time elapsed after the face has passed at the vertical of the point being considered,
- t_0^R, m^R and σ^R are parameters.

It can also be said that the closer the bed is to the seam being mined, the shorter the delay t_0^R, the shorter the time required to reach maximum intensity t_1^R, and the higher the maximum emission speed. In other words, a bed in close proximity releases its gas earlier, faster and at a higher flow rate. A distant bed releases it later, for a longer period and with a lower flow rate.

Figure 10 represents the emission curves for 3 beds located at different distances.

In order to represent these phenomena, it can be considered that the values of t_0^R and t_1^R obey parabolic laws as a function of the distance between the bed i being considered and the mined seam, d^R (i) :

$$t_0^R(i) = \alpha^R \left[d^R(i)\right]^2 \quad (4)$$

(parabolas 1 and 1' on the Figure 10)

$$t_1^R(i) = \beta^R \left[d^R(i)\right]^2 \quad (5)$$

(parabolas 2 and 2' on the Figure 10)

and that the maximum value of the function f^R obeys a hyperbolic law :

$$\frac{1}{\sqrt{2\pi}\sigma^R(i) t_1^R(i)} \exp\left[\frac{-\left[\mathrm{Log}\left[t_1^R(i)\right] - m^R(i)\right]^2}{2\left[\sigma^R(i)\right]^2}\right] = \frac{1}{\gamma^R d^R(i)} \quad (6)$$

$$t_1^R(i) = e^{m^R}(i) - \left[\sigma^R(i)\right]^2$$

(characteristic of the log-normal distribution) (7)

where σ^R, β^R and γ^R are parameters.

In these last expressions, all the parameters t_0^R , t_1^R , m^R and σ^R are expressed as a function of i, the index representing the different beds contained in the volume of influence. These expressions are the same for the roof and floor beds, but with different parameter values (F indexes for the latter).

We know that the face starting phase corresponds to an expression of the volume of influence while the subsequent phase corresponds to its translation. During the first phase, there are longer delays before emission begins from that part of the bed being considered than in the second phase. This phenomenon can be modelled by parameterizing parabolas 1, 2, 1' and 2' in the following way (for the roof) :

$$\alpha^R = \alpha_0^R + \varepsilon \left[\frac{L_c}{L}\right]^2 \qquad (8)$$

where :

- α_0^R is a constant,
- L is the cumulated advance of the face from the starting,
- L_C is the critical advance length,
- $\varepsilon = 0.1$ or 0.05 for example.

The parabolas 3, 4, 3' and 4' corresponding to the starting period tend respectively towards parabolas 1, 2, 1' and 2', which correspond to the subsequent phase and are steady. The parameters β and γ are taken to be constant (β_0 and γ_0).

Having mathematically expressed all the physical phenomena, the total CH_4 emission during a given period, on a given day, j, for example, can be expressed as follows :

$$G(j) = \frac{D_S}{100}\Big[P_{MS}A(j) + \sum_{i=1}^{R} P_R(i) \sum_{k=1}^{j} A(k) \int_{j-k}^{j-k+1} f_i^R(t)\,dt + \sum_{i=1}^{F} P_F(i) \sum_{k=1}^{j} A(k) \int_{j-k}^{j-k+1} f_i^F(t)\,dt\Big] \qquad (9)$$

where :

- D_S is the specific emission calculated (see chapter 2) in m^3/m of advance,
- P_{MS} is the share of this specific emission produced by the mined seam, in %,
- P_R (i) is the share of this specific emission produced by bed number i at the roof, in %,
- P_F (i) is the share of this specific emission produced by bed number i at the floor, in %,
- R is the number of beds at the roof,
- F is the number of beds at the floor,
- A(j) and A(k) are the face advances on days j and k respectively, in m,
- $f_i^R(t)$ is given, for bed i, by expression (3) and $f_i^F(t)$, by a similar one for the floor.

with :

- $\sigma^R(i)$, $t_0^R(i)$ and $m_0^R(i)$ obtained by resolving the system of equations (4) to (8),
- $\sigma^F(i)$, $t_0^F(i)$ and $m_0^F(i)$ obtained by resolving a similar system for the floor.

The CH_4 emission, G(j) is expressed as a function of six parameters, $\alpha_0^R, \beta_0^R, \gamma_0^R$ for the roof and α_0^F, β_0^F, γ_0^F for the floor.

The practical method consists in adjusting the parameter values on a reference face by minimizing the discrepancies between the calculations and measurements for the working. The least error squares method can be used for this, for example. In practice, if the CH_4 emissions are calculated on a day-to-day basis, they can be marred by errors. For this reason, it is preferable initially to consider a weekly CH_4 emission.

After obtaining the optimum values for the six parameters and checking their validity, the same formulae can subsequently be used to make real predictions for other faces.

CONCLUSIONS

Here, two methods are presented for a dynamic prediction of firedamp emission in longwalls :

- a statistical method has been defined and has already given interesting results for several workings, but normally cannot correctly represent the starting period for the face,
- the mathematical bases have been laid for an empirical method closer to the physical reality of the phenomenon. This method will need to be validated during implementation.

The emission of firedamp around a mining structure is an eminently complex problem. It is very difficult to equate the problem as a whole, given the number of parameters involved and, in particular, the practical difficulty of apprehending the values of these parameters. Thus, what is proposed here is a pragmatic approach to the problem.

These methods can provide the operator with a prediction of the firedamp emission. He needs tools to optimize the mining work, that is, to adjust the human and material resources available to the real production capacities of a working.

The prediction methods described here are an improvement in this respect and finally should result in better productivity for workings as well as greater safety.

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Weekly firedamp emission

U.E. Reumaux - Face Frieda 5 South block 1 960/1036

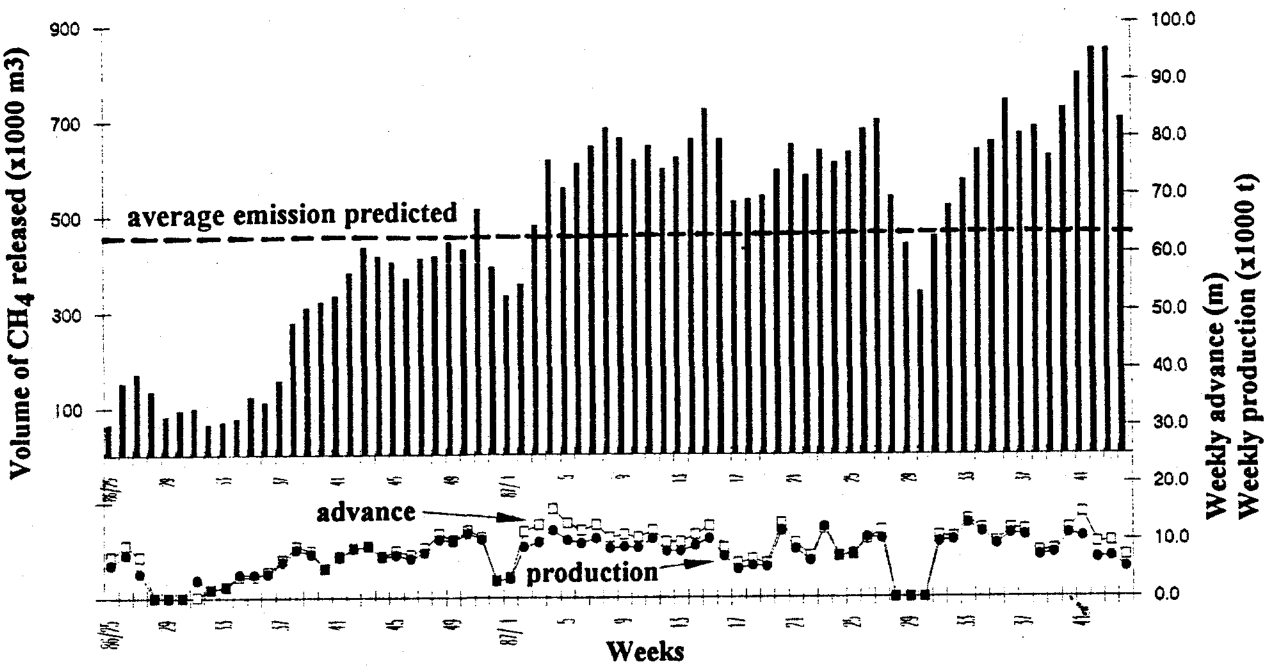

Figure 1

DETERMINATION OF AVERAGE MULTIPLE REGRESSION PARAMETERS BETWEEN WEEKLY EMISSION AND THE FACE ADVANCE

REGRESSION ON DATA WHOSE CUMULATED FACE ADVANCE IS GREATER THAN 220 M

N°	Longwall	Mine	Correlation coefficient r^2	Degrees of freedom	Parameter values			
					Week n	Week n-1	Week n-2	Constant
					a_n	a_{n-1}	a_{n-2}	C_a
1	Louise II bis	Reumaux	0.62	31	223	124	76	5976
2	Irma II sud	Reumaux	0.47	40	143	41	50	5405
3	Louise I bis	Reumaux	0.84	18	399	219	56	2593
4	K pan.2	Forbach	0.64	48	344	167	127	6135
5	H2 pan.1	Forbach	0.93	10	413	268	66	4829
6	Albert 9.6.0	La Houve	0.77	12	451	116	46	7700
7	Frieda 5 Sud pan.1	Reumaux	0.50	36	168	116	112	5650
AVERAGE PARAMETER VALUE					306	150	76	5470
STANDARD DEVIATION					117	70	29	1434

TABLE 1

Model for predicting the average CH_4 emission in a face

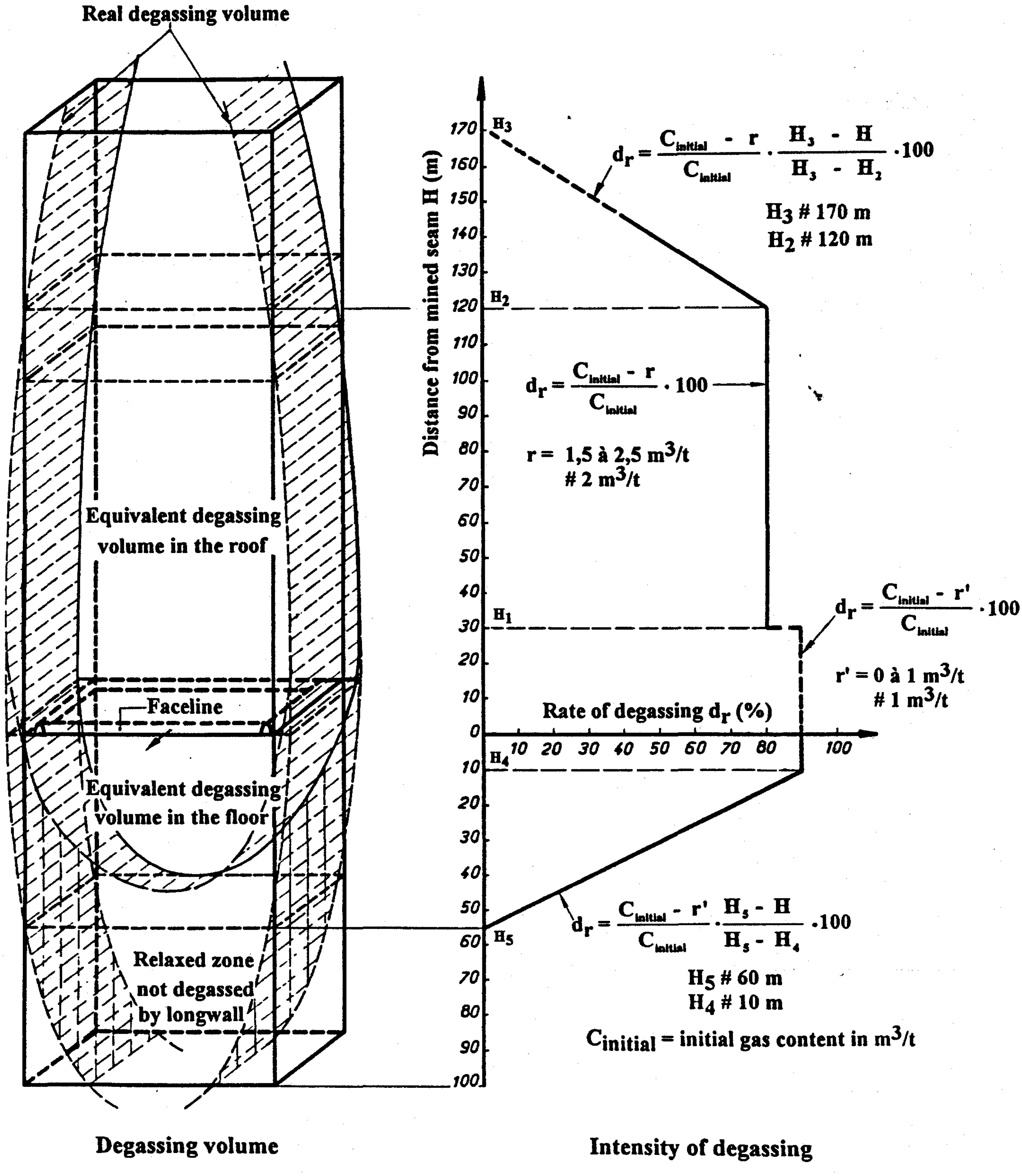

Figure 2

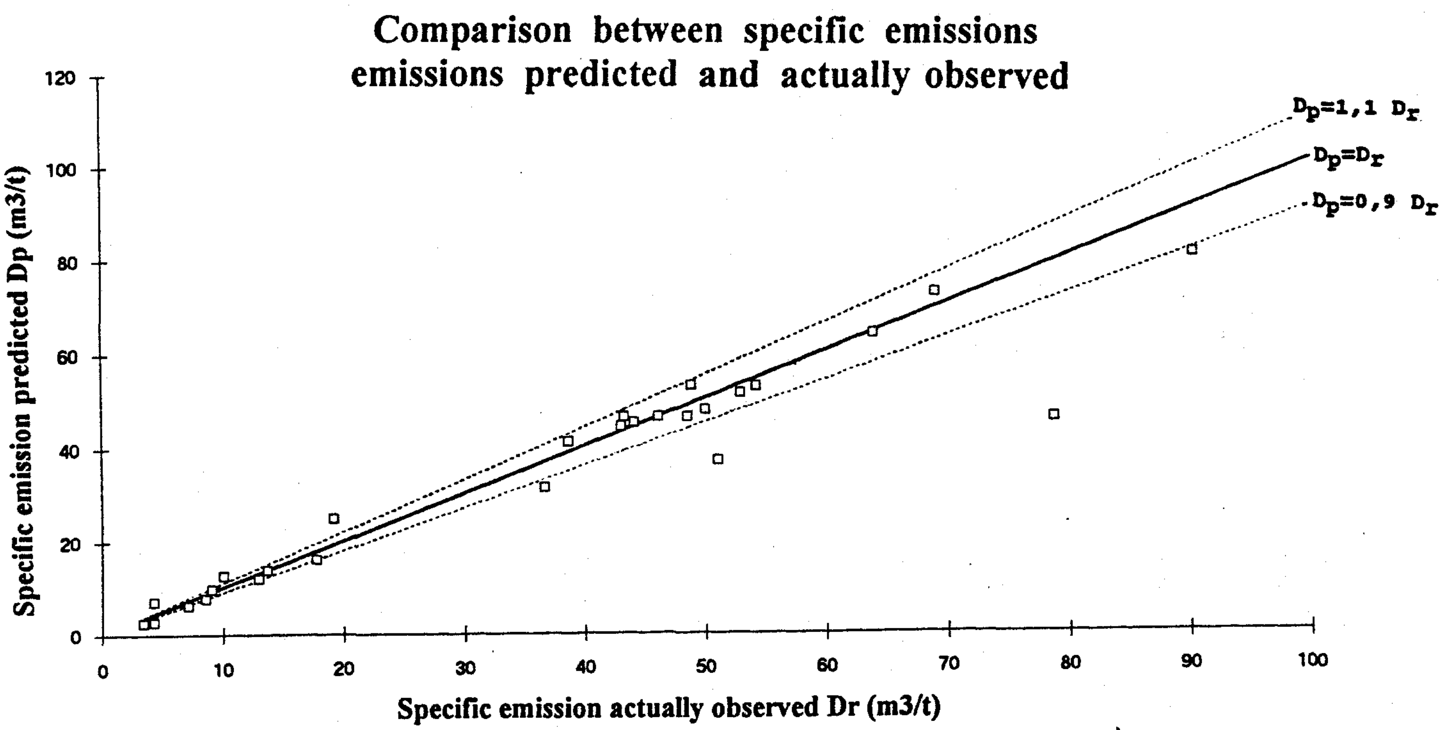

Figure 3

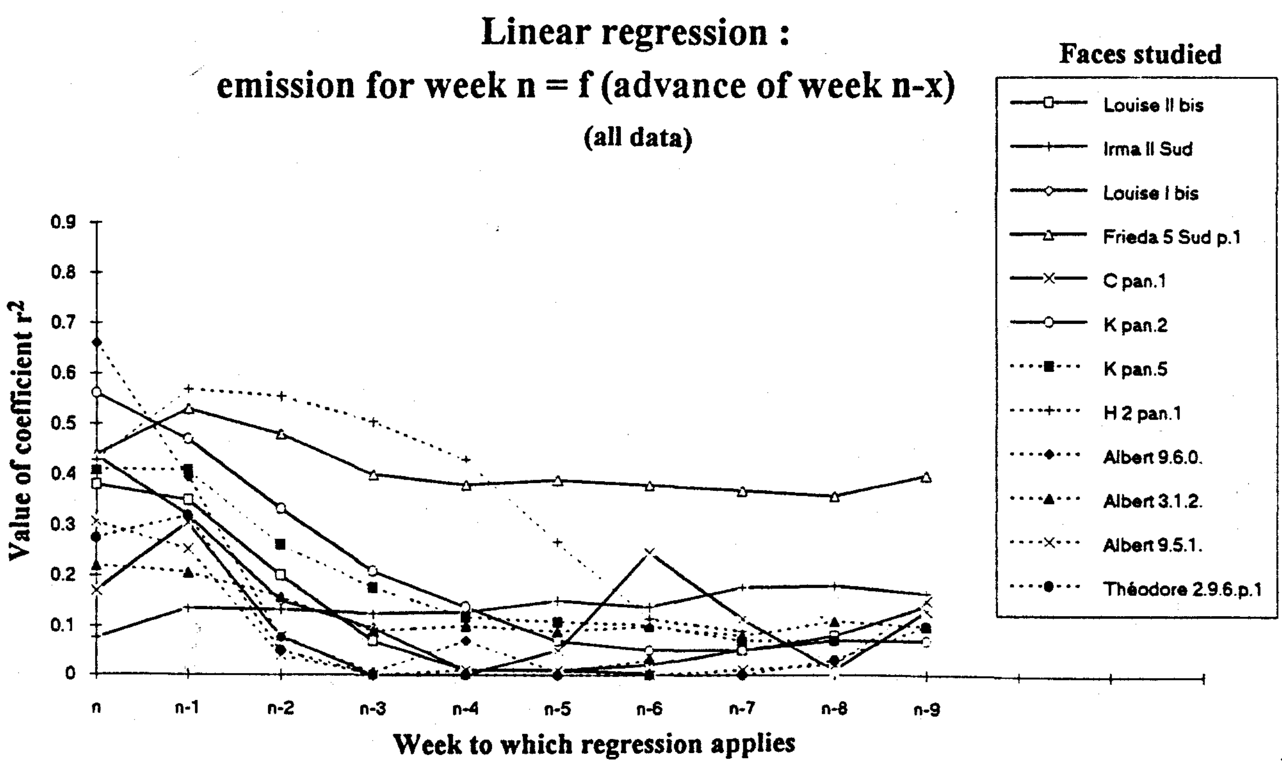

Figure 4

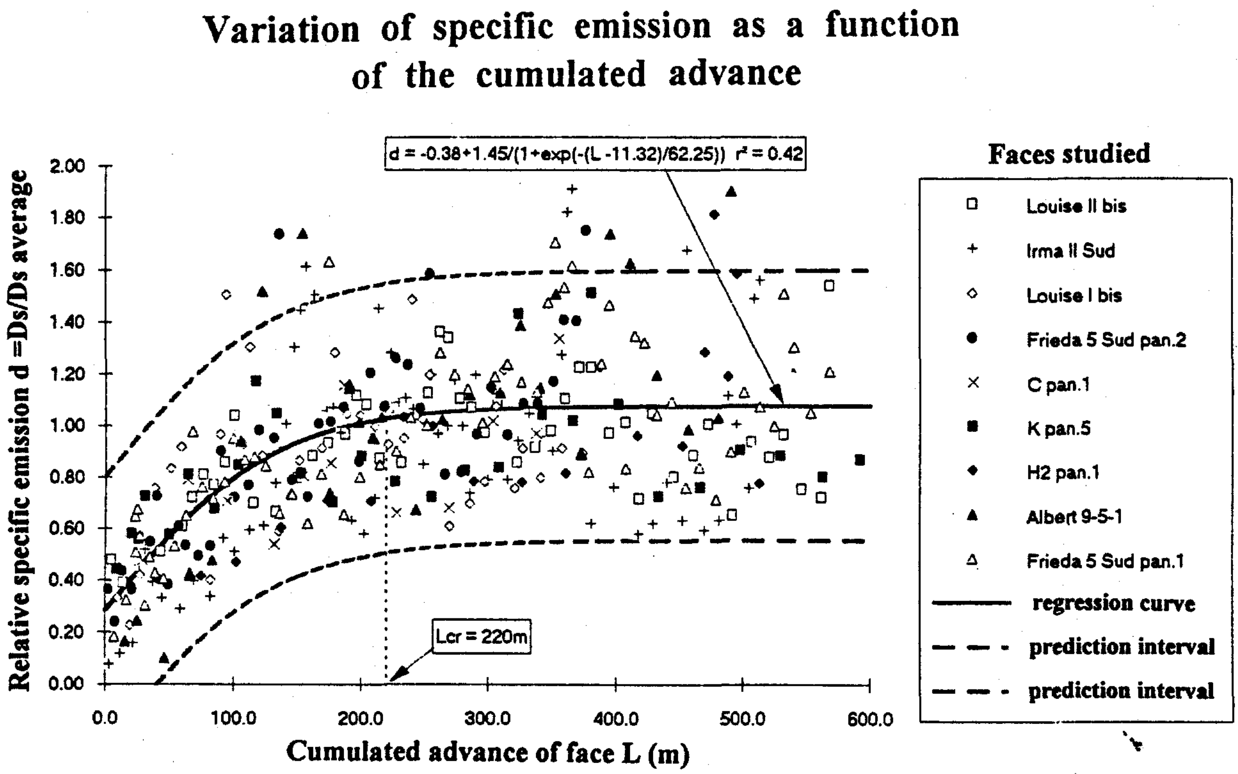

Figure 5

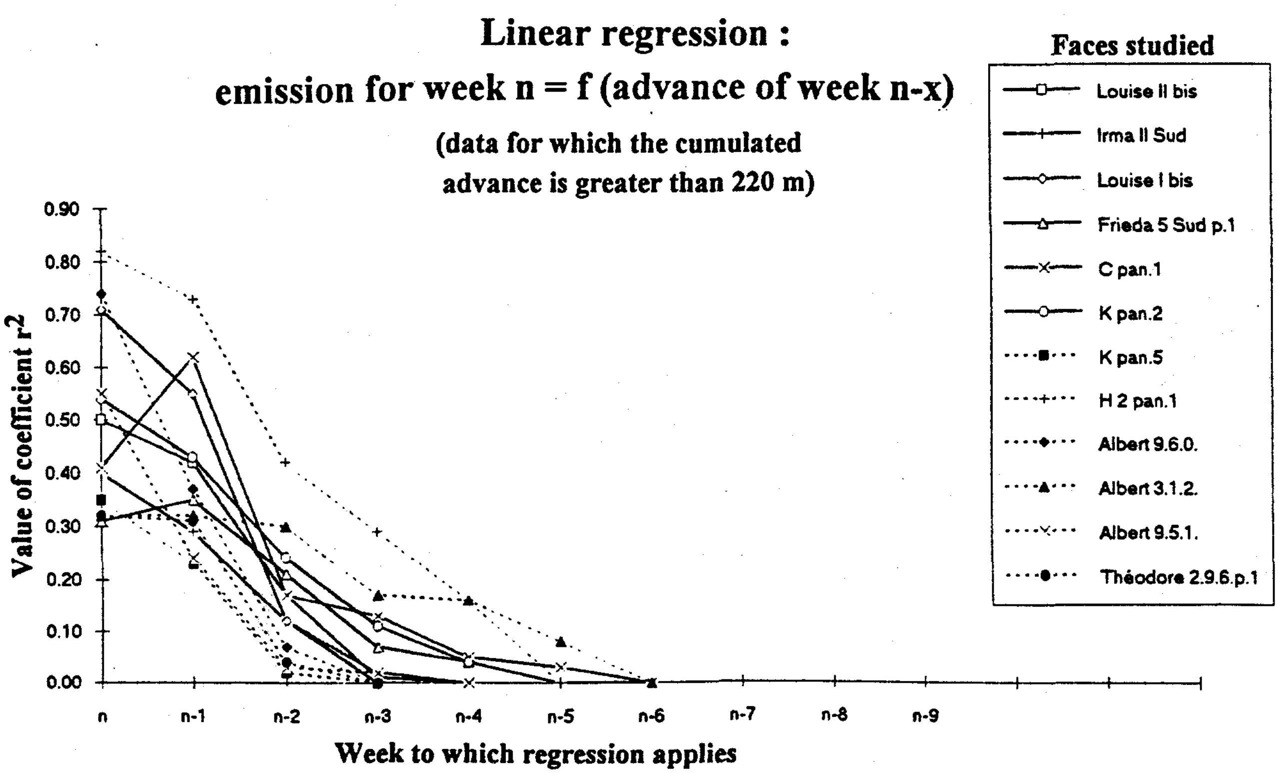

Figure 6

Variation of the CH_4 emission rate as a function of time

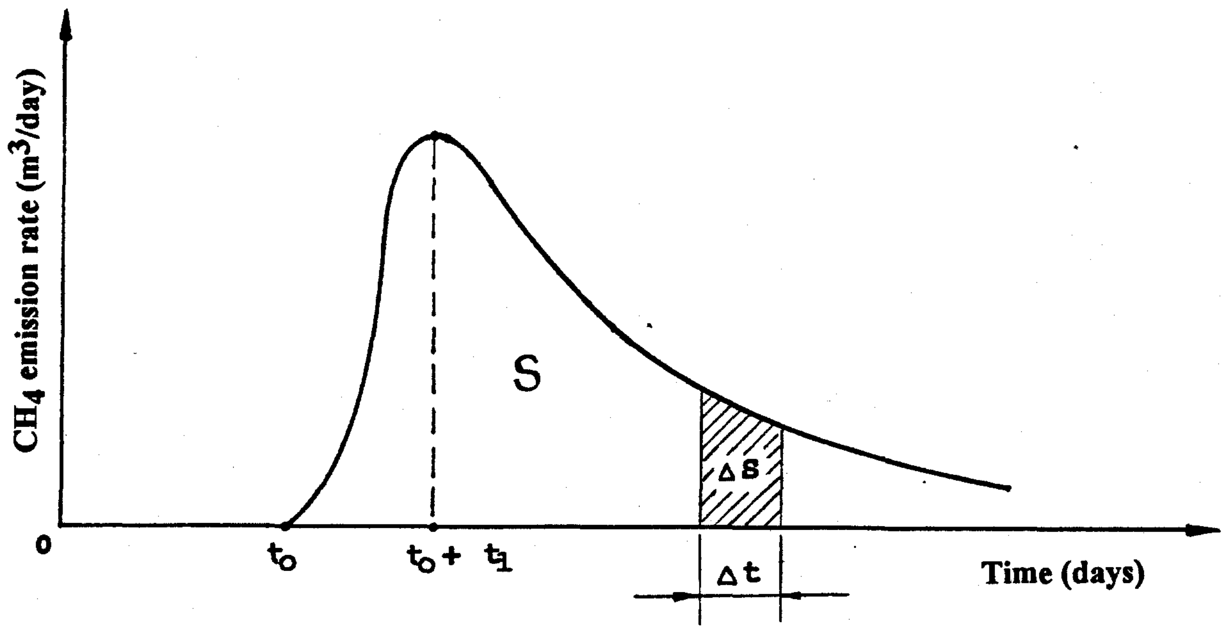

Figure 9

Shape of the emission curve as a function of the vertical distance of the beds from the mined seam.

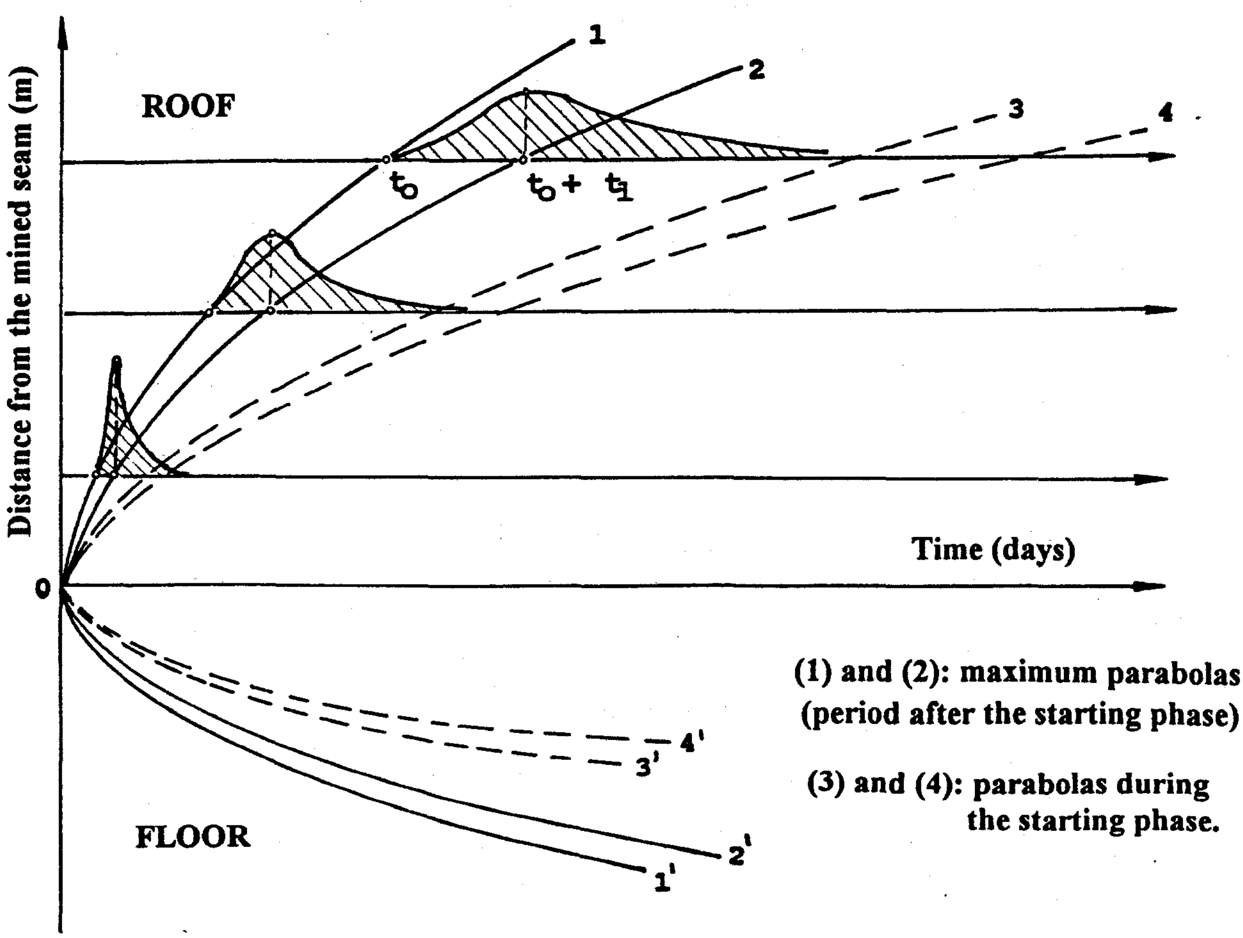

Figure 10

Prediction of weekly CH_4 emission as a function of the advance

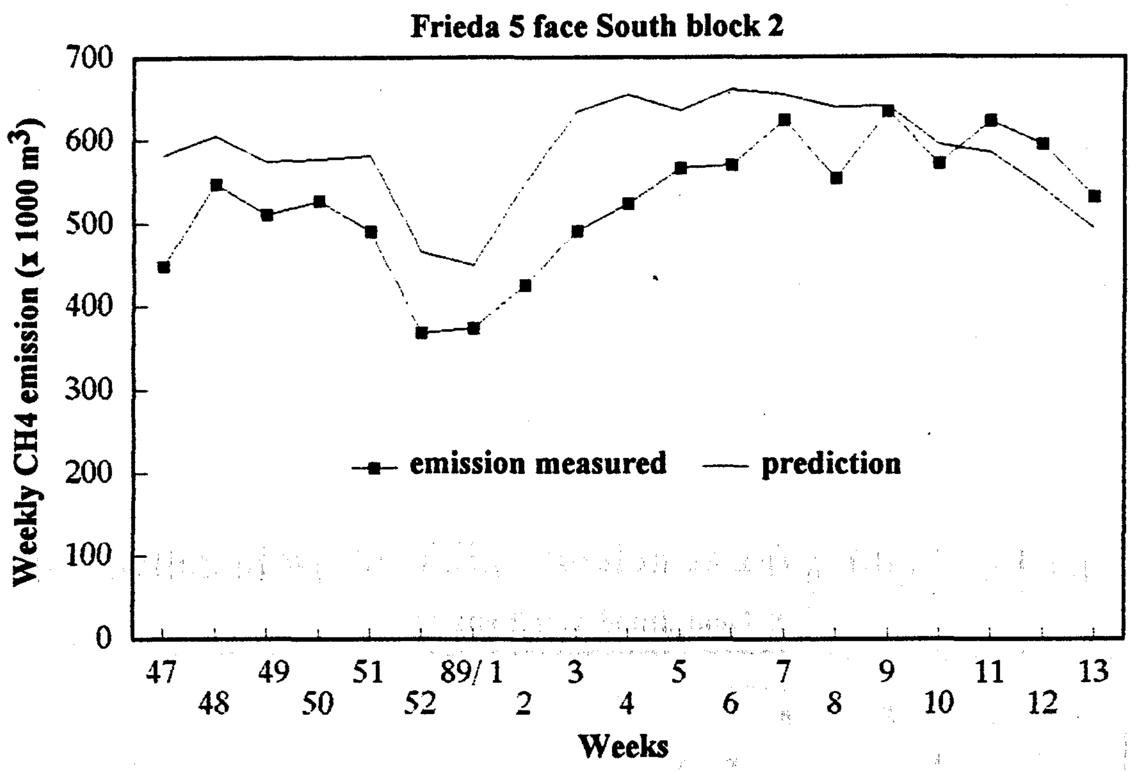

Figure 7

Prediction of weekly CH_4 emission as a function of the advance

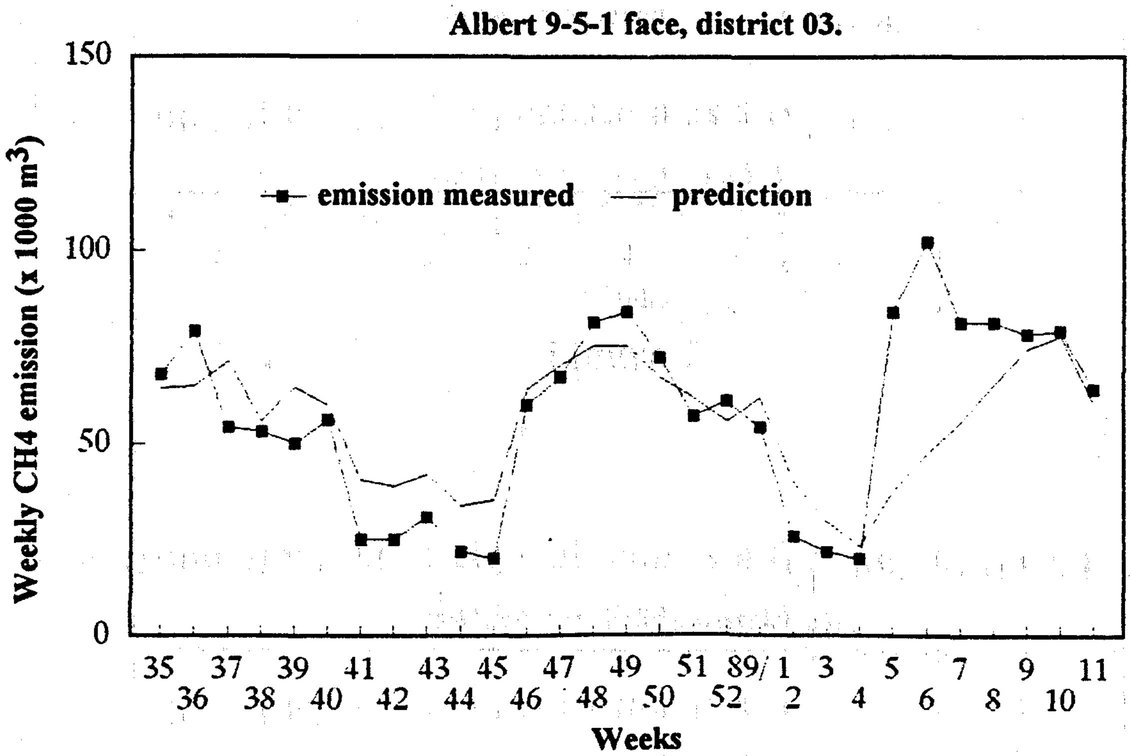

Figure 8